(NASA-CR-4147) TURBOFAN FORCED MIXER LOBE FLOW MODELING. PART 3: APPLICATION TO AUGMENT ENGINES Final Report (Pratt and Whitney Aircraft) 32 p

N89-10025

CSCL 01A

Unclas

H1/02 0168499

NASA Contractor Report 4147

Turbofan Forced Mixer Lobe Flow Modeling

III—Application to Augment Engines

T. Barber, G. C. Moore,
and J. R. Blatt
United Technologies Corporation
Pratt & Whitney Engineering Division
East Hartford, Connecticut

Prepared for
Lewis Research Center
under Contract NAS3-23039

National Aeronautics
and Space Administration

Scientific and Technical
Information Division

1988

FOREWORD

The overall objective of this NASA program has been to develop and implement several computer programs suitable for the design of lobe forced mixer nozzles. The approach consisted of extending and existing analytical nacelle analysis to handle two stream flows where one of the streams is at a higher energy. Initially the calculation was set up to handle a round, free mixer including satisfying the Kutta condition at the trailing edge of the mixer. Once developed and calibrated, the same analysis was extended to handle periodic boundary conditions associated with typical engine forced mixers. The extended analysis was applied to several mixer lobe shapes to predict the downstream vorticity generated by different lobe shapes. Data was taken in a simplified planar mixer model tunnel to calibrate and evaluate the analysis. Any discrepancies between measured secondary flows emanating downstream of the lobes and predicted vorticity by the analysis is fully reviewed and explained. The lobe analysis are combined with an existing 3D viscous calculation to help assess and explain measured lobed data.

The program also investigated technology required to design forced mixer geometries for augmentor engines that can provide both the stealth and performance requirements of future strategic aircraft. For this purpose, UTC's available mixer background was used to design several preliminary mixer concepts for application in a exhaust system. Based on preliminary performance estimates using available correlations, two mixer configurations will be selected for further testing and analysis.

The results of the program are summarized in three volumes, all under the global title, "Turbofan Forced Mixer Lobe Flow Modeling". The first volume is entitled "Part I - Experimental and Analytical Assessment" summarizes the basic analysis and experiment results as well as focuses on the physics of the lobe flow field construed form each phase. The second volume is entitled "Part II - Three Dimensional Inviscid Mixer Analysis (FLOMIX)". The third and last volume is entitled "Part III - Application to Augmentor Engines".

TABLE OF CONTENTS

I. INTRODUCTION AND SUMMARY

Future gas turbine engines for military tactical fighter applications are expected to require a moderate engine bypass ratio cycle (BPR) (0.6 to 1.2) that will operate with very high primary combustor exit temperature. Anticipated missions include long subsonic cruise legs as well as augmented supersonic dash capability. An advanced augmentor compatible with this type of engine cycle and emission will require low nonaugmented (dry) thrust specific fuel consumption (TSFC), dependable augmentor ignition, stable operation in the upper left-hand corner (ULHC) of the flight envelope, high core stream temperature accommodation, and high combustion efficiency within the confines of a short afterburning length. The use of enhanced survivability features is also an important consideration in the augmentor design.

Military engines frequently need large quantities of thrust for short periods of time to aid in takeoff or combat capability. The addition of an augmentor to an engine can provide such thrust increases but at the penalty of increased duct length and engine weight. The added mixing length, many times that of a non-augmented engine, is needed for increased residence time to complete the combustion process. The addition of a forced mixer to augmentor is an effective means for obtaining increasing mixing efficiencies without the added duct penalties. The mixing in current augmented engines (without forced mixers) is in the 50 to 70 percent range. Addition of a mixer could bring this figure up to the 90 percent range and thus provide an increased dry thrust and "TSFC". Furthermore, while augmentors in turbofan engines can suffer from rumble and acoustic interaction between the combustion process and the engine geometry due to burning conditions in the cold gas stream, incorporation of a mixer provides a method of sitting the flameholders in a hot gas environment and thereby improves the rumble characteristics of the augmentor.

In the current NASA contract two augmentor concepts have been indentified as having features attractive to military engines:

- SWIXER (Swirl-Mixer) Augmentor
- Mixer Flameholder Augmentor

The SWIXER augmentor concept uses variable swirl vanes at the discharge of a convoluted, forced mixer to improve nonaugmented TSFC through enhanced mixing. It also has the advantage of accelerated burning rate (which yields short duct length and weight) of a swirl augmentor. The SWIXER system consists of an annular pilot burner at the outer diameter of the combustible gas mixture, with variable vanes incorporated in the mixer to swirl the exit flow providing enhanced flame propagation by increased turbulence and bouyancy forces. Conceptual design studies indicate that the SWIXER augmentor shows a gain in mission range due to low-pressure loss along with high combustion efficiency. Less percent mixing was determined for this concept because of the amount of fan airflow used with the outer diameter (OD) pilot, which enters the augmentor in an axial direction. The resultant percent mixing is predicted to be lower for a confluent flow system.

The flameholder mixer augmentor concept uses a convoluted, forced mixer in series with a bluff body flame stabilizer. Through improved mixing with low-pressure loss, the mixer flameholder augmentor addresses the primary mission/cycle requirement of low nonaugmented TSFC. Augmented performance is comparable to that of a state-of-the-art bluff body stabilized augmentor. The flameholder mixer system consists of V-gutter flameholders being used as flame ignition sources incorporated within the mixer. Conceptual design studies indicate that the mixer flameholder augmentor has the largest gain in mission range due to its predicted high percent mixing and lowest weight. Table I provides a summary of predicted performance and design features for these two augmentor concepts.

TABLE I
AUGMENTOR CONCEPT SUMMARY

Augmentor Concept	Advantages	Disadvantages
Swirl-Mixer (Swixer)	o Good Dry Mixing o Low Dry Pressure Loss o Short Burning Length o ULHC Stability	o Complex o Heavier
Flameholder Mixer	o High Dry Mixing o Short Burning Length o ULHC Stability o No Variable Geometry o Low Weight	o Higher Dry Pressure Loss

The current NASA contract considers two different designs for each augmentor concept. The design were tailored for installation on a JT15D-4 engine, already available for possible full scale testing of potentially attractive designs. One candidate design for each augmentor concept was selected for more complete aerodynamic design efforts, resulting in planar equivalent models for detailed experimental testing. The proviso requiring the use of the JT15D-4 as a design engine introduced some difficulties. While the bypass ratio is in the desired range for a subsonic bomber application, the engine is currently operated as a non-mixed flow engine: that is, the fan and core flows exit through individual
nozzles with flow through the nozzle at the sea level static takeoff point that was used as a aerothermal design point. Augmentors require variable area nozzles to operate without affecting the gas generator operation and work best when these nozzles are choked. In order to simulate these effects, it was assumed for thrust calculations that the engine was operating in an altitude stand with 14.7 psia at the inlet and 9.0 psia at the nozzle. This actually represents a flight point of approximately 13,000 feet at 0.87 Mach number.

II. DESIGN OF MIXERS FOR AUGMENTOR ENGINES

For several years empirical design systems, based on available data, have been used to assist in the design of mixed flow nacelles. These systems typically consisted of correlations relating total pressure loss and mixing characteristics to key geometrical parameters. These correlations however rarely consider the actual flow path and its aerodynamic history. Mixer performance has been largely attributed to the following geometrical correlating parameters:

<u>Percent Mixing</u>

Mixing length ~ L_m/R_{mean}

Penetration ~ $A_{primary}/A_{duct}$

Lobes

"<u>Excess" Pressure Loss</u>

Turning Rate ~ L_m/h

Penetration

Lobes

Lobe Aspect Ratio ~ X/h

These geometrical parameters are defined using the nomenclature shown in Figure 1, with Lm referring to the length of the mixer from its cross-over location to the lobe exit plane and Rm referring to a mean radius for the mixer lobe. The term "excess" pressure loss refers to those viscous contributions beyond that of an attached boundary layer, i.e. base region losses, separation, etc.

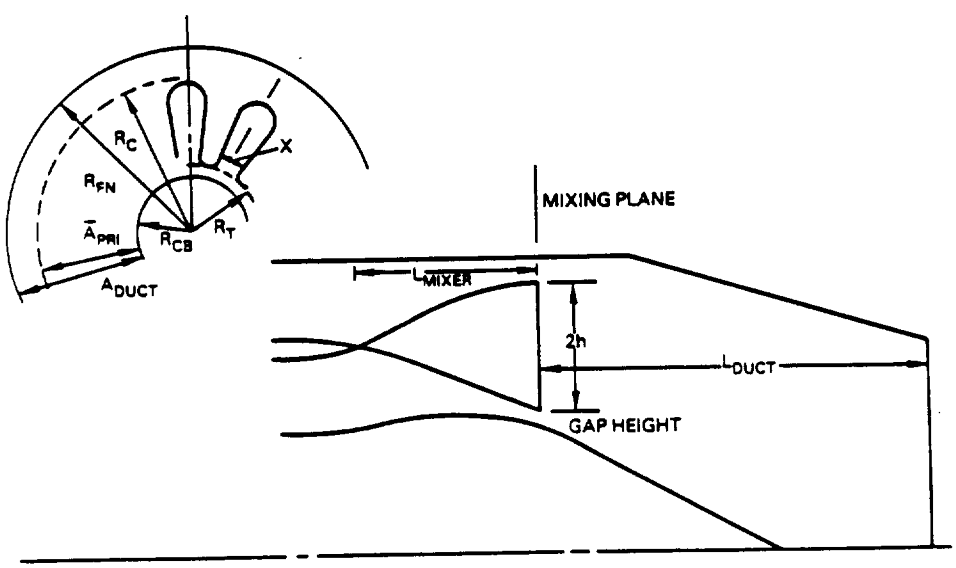


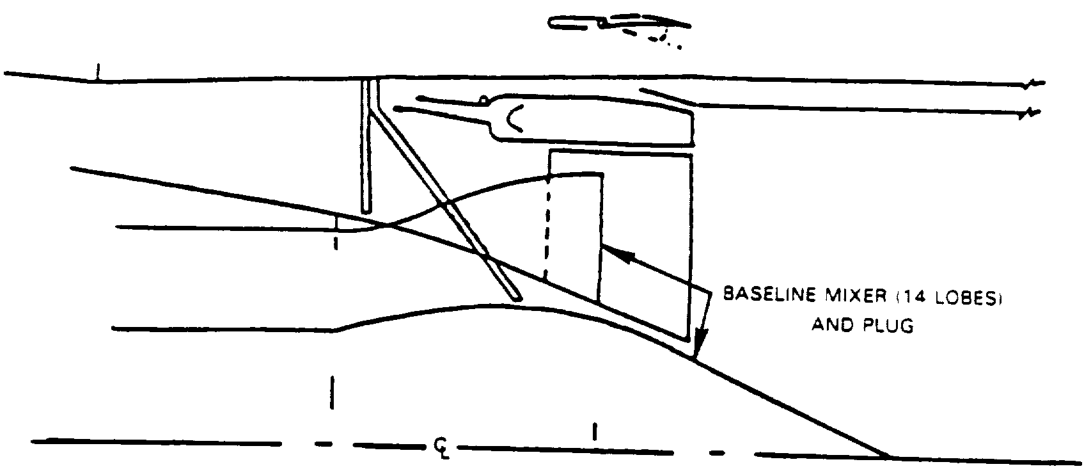
Figure 1 Mixer Performance Parameter Nomenclature

A. Baseline SWIXER

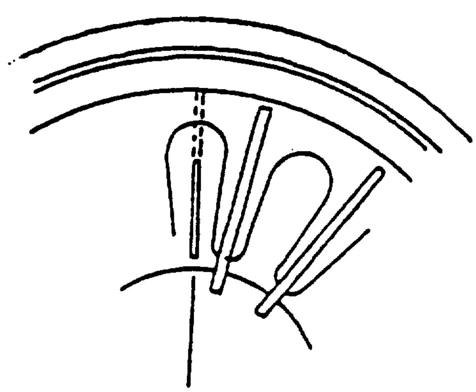
Design Description

The baseline swixer, as shown in Figure 2, utilizes a very deep penetration mixer with 14 lobes. Variable swirl vanes are located in the center of the cold chutes. The vanes are contoured so as to minimize pressure loss while in the axial flow configuration and yet maintain attached flow when turned at 25 degrees to swirl the flow. A pilot is provided to initiate combustion in the flow, but a cooling liner must be used to maintain the case and nozzle temperatures within acceptable limits. Fuel injection is provided by spraybars in both the hot and cold flows. The fuel is injected in a radially zoned configuration from the OD towards the ID with each successive zone.

The tailcone has an extension past the plane of the reactant ignition. The base of the swixer vane is mounted into the tailcone and the bearing surface for the pivoting pin is inside the tailcone being cooled by fan air. The swirl vanes pivot at the trailing edge of the mixer.



SIDE VIEW



END VIEW

Figure 2 Preliminary Design Views of Baseline Design SWIXER No. 1

Rationale

The baseline swixer was designed using conventional augmentor cooling liner technology and proven swirl pilot ignition techniques. Deep mixer penetration was achieved by placement of the swirl vanes only in the cold chutes thus forcing the cold chute area to be enlarged to maintain a constant flow area at the trailing edge of the mixer where the static balance plane is located. Placement of the vanes in the cold chute also reduced the dry pressure loss of the vane by sitting it in the lower velocity flow. The vane will transmit less heat to the bearing surface and, thus, provide longer life and more reliable operation by positioning in the cold stream.

The pilot has been placed at the outer diameter of the burning flows for several reasons:

a) To take advantage of the buoyancy forces in existence when a hot compressible fluid is located at the OD of a swirling flow

b) To avoid interference with the trailing edge vortices of the mixer.

c) To shorten the required fuel lines and provide for low blockage mounting the pilot apparatus

d) To site it in an area with excellent cooling airflow since it will be operating with flows at approximately stoichiometric conditions.

Spraybar fuel injection is provided because of the use of a mixer. Although sprayrings are, in many respects, a superior method of fuel injection when used with a swirl augmentation system (the zoning lines up with the annular zone requirements of the OD piloted system and they are of lighter weight than spraybar system due to the absence of circumferentially manifolding on the OD of the case), the many penetrations of the mixer geometry required by a circumferential sprayring render its assembly and maintenance very difficult.

The use of spraybars minimizes mixer penetrations and, since the spraybars are oriented radially, provides for removal for maintenance or replacement without interference from the mixer.

Zoning is provided by the use of multiple bars in any one chute. The bars are of varying lengths and have fuel injection orifici at different radius. Fuel is directed toward the outer radius in both the hot and cold flows first in the area adjacent to the pilot.

B. Advanced SWIXER

Design Description

The advanced swixer, shown in Figure 3, utilizes a six lobe design with the variable angle swirl vanes in the center of the cold chutes, as was done in the baseline. The surface of the mixer incorporates a multiple of slots oriented to capture air from the fan stream and inject it into the core stream. A swirl pilot is incorporated to provide ignition capability at low fan stream temperatures. Fuel injection spraybars are located in the mixer walls and are sequenced to provide annular zones starting at the pilot radius and progressing inward. The trailing edge of the mixer chutes are parallel to the swirl vanes rather than radial.

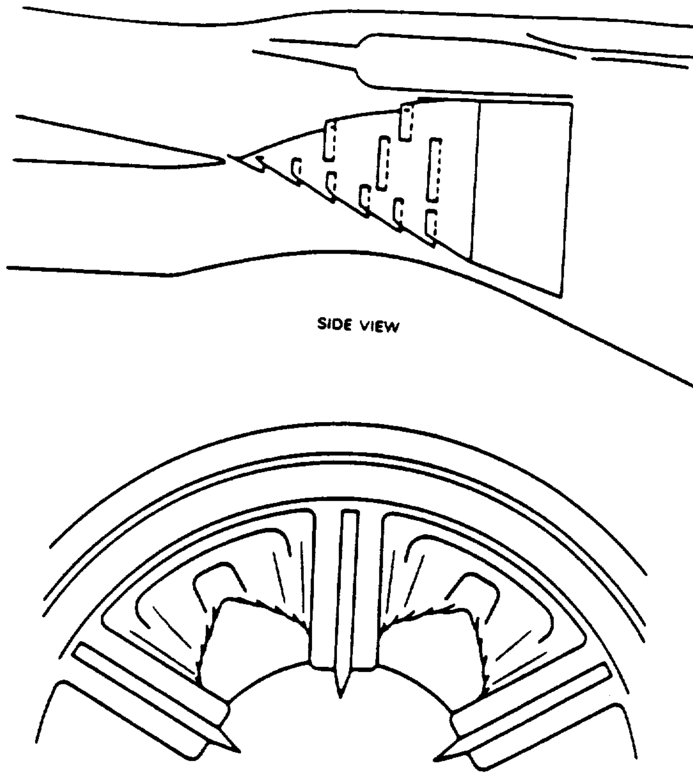


Figure 3 Preliminary Design Views of "Gilled" Design SWIXER No. 2

Rationale

The design goal of this concept was to maximize the mixing of the fan and core streams while reducing the pressure loss and the tendency for separation in the mixer chutes. The gilled SWIXER concept is an attempt to do both. The incorporation of slots in the mixer surface introduces fan air to the hotter core air before the trailing edge of the mixer is encountered. The presence of the mixer increases the contact area between the hot and cold streams relative to that achievable with a circular splitter plane. Incremented slot injection acts to prevent separation on either side of the mixer surface by drawing the boundary layer from the fan side of the mixer and injecting it into the lower energy boundary layer on the core side surface.

The fuel injection spraybars are located in the mixer walls to reduce pressure drop. The swirl vanes are placed in the fan chutes to reduce the pressure loss and provide for lower temperatures at the movable interfaces. The Lamalloy tail cone provides another source of cold air to enhance the mixing characteristics of the augmentor through a porous surface.

The mixer has been reduced to a six lobe design due to the quantity of air being injected into the core chute. A larger number of fan mixing chutes would increase the airflow to the core side and reduce the flow area of the fan chute to a level where either chute penetration would suffer or too severe a narrowing of the chute at the swirl vane station would adversely affect the flow over the vanes.

C. Candidate SWIXER Aerodynamic Design

The alternate approach taken in the advanced SWIXER configuration is to more aggressively promote core flow/fan flow mixing by adding a series of cold chutes along the lobed surface. This so called "gilled" design is shown in Figure 3. The basic concept is patterned after the single slot approach used by Sokhey & Farquhar (Ref. 1) of The Boeing Company. Their approach, which used a simple slot normal to the crest line of the lobe to enhance the mixing process, incurred a performance penalty. For a swixer mission however this penalty need not be a relevant mission parameter. Additionally, a porous plug of lamalloy is included to further bleed cold air into the core flow. The baseline JT15D SWIXER configuration needs to be redesigned to reflect the different mass flow splits. Considering the scope of this program and the intent of using the selected SWIXER design for analytical studies, it was jointly agreed that the baseline SWIXER be approved for more detailed aerodynamic design and subsequent fabrication and testing.

SWIXER Aerodynamic Design

Two design exercises were conducted to define the baseline SWIXER configuration. A first pass, SLTO design point configuration was generated by defining the swixer augmentor components and their airflow requirements and integrating them with the Baseline SWIXER. The augmentor components include a pilot, swirl vanes, and spray bars. A second pass design exercise was conducted for the purpose of reoptimizing the mixer shape relative to the augmentor components, and for the purpose of reducing the possibility of flow separation in the fan passage. A comparison of the first pass SWIXER and revised SWIXER configuration are shown in Figure 4. The following changes were made to the first pass design:

1) The mixer lobe penetration and turning rate were reoptimized relative to the new mixing duct geometry required by the augmentor components.

2) The mixing plane areas were resized to be compatible with the airflow requirements of the pilot and the swirl vane blockage.

3) The number of lobes was reduced from 14 to 12 to accommodate the swirl vanes.

4) The fan valley angle was reduced from 22 degrees to 17 degrees.

5) The plug contour was redefined.

6) The outer diameter of the fan duct upstream of the mixer was reduced.

A comparison of design characterization for improved SWIXER design and the Baseline SWIXER is shown in Table II.

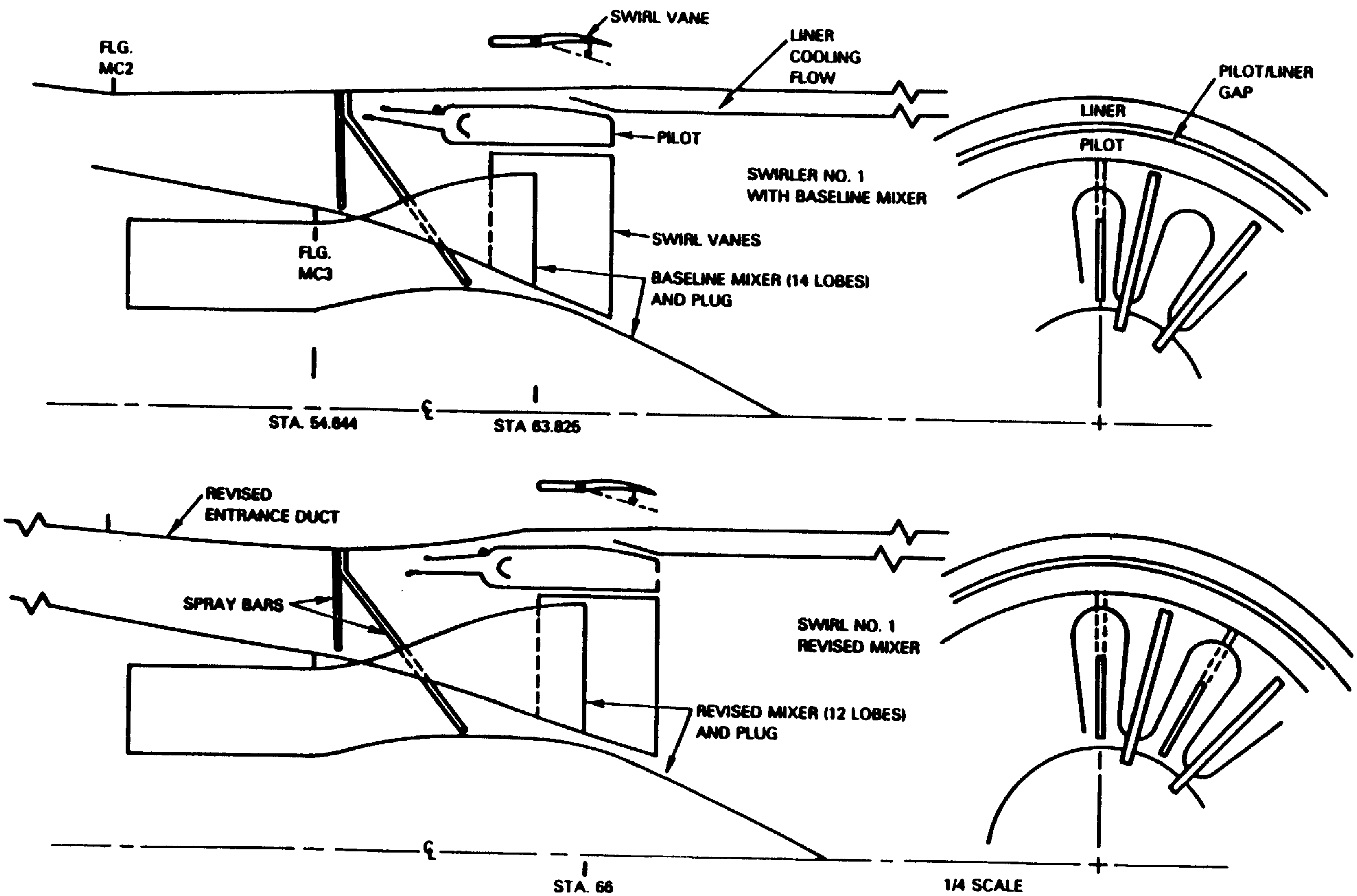


Figure 4 A Comparison of First Pass and Revised Versions of SWIXER No.1

TABLE II
DESIGN CHARACTERISTIC COMPARISON

SWIXER NO. 1 AND SWIXER FINAL

	Swixer No. 1	Swixer Final
No. of Lobes	14	12
Mixing Length		
(L_{TP}/D) T/P Dia.	1.25	1.096
(L_{TP}/D) Pilot Dia.	N/A	1.25
Penetration		
Relative to T/P	77%	64%
Relative to Pilot	N/A	88%
Scallops	None	None
Scarf Angle	0°	0°
Lobe Sidewall Contour	Radial Walls	Radial Walls
Primary Flow Path	Constant Area	Constant Area
Fan Flow Path	Accelerating	Accelerating
Mixing Duct	Constant Area	Diffusion-Constant Area
Overall Mixing Turning Rate (Lm/H)	1.579	1.830
Primary Turning Rate (R/)	0.245	0.246
Fan Valley Angle	22°	17°
Gap Size (A_{GAP}/A_{PRI})	12%	11.9%
Gap Height ($H_{GAP}/2^*F_c$)	0.46	0.32
Approx. Displacement Thickness Ratio in Fan Valley ($^*R_c$)	0.67	0.90
Aspect Ratio	0.305	0.285

An improved SWIXER configuration was designed using the same design criteria used for the Baseline SWIXER (reference). The mixer optimization process was conducted by defining a virtual flow path bounded on the outside by the pilot and a slip line extending rearward from the pilot. This approach assumes that mixing between the fan and primary flow passing through the mixer is dominated by the mixer and that the mixing process between the pilot flow and mixer flow is dominated by the SWIXER design. Performance trades between estimated mixing gains and pressure loss penalties were conducted for the system within this envelope with the aid of in-house mixer performance correlations. This resulted in the selection of a new mixer configuration with higher penetration and longer length than the baseline. This configuration is estimated to produce a high level of mixing (87.6% within the virtual flow path) with a tailpipe length (27.177 inches) that is not expected to be longer than required by the SWIXER components. The mixer penetration relative to the pilot was increased from 77% to 88% and from 56% to 64% relative to the tailpipe. The new mixer is 2 inches longer. Generally, higher penetration mixers are longer in length because of a performance trade between increasing mixing gains and increasing turning losses.

The mixer exit areas were resized to account for swirl vane blockage and reduced fan flow through the mixer lobes. The intent is to cause the component operating characteristics of the JT15D-4 to remain essentially unchanged if the engine is operated at SLTO with the SWIXER. The fan flow through the mixer lobes is reduced relative to the baseline mixer because the pilot flow and cooling flow (20% of the fan flow at SLTO) bypass the mixer. The swirl vanes are estimated to effectively block 37.915 sq. inches of the fan lobe area at the mixing plane. The vanes are approximately 0.5 in. wide at the mixer exit and are curved in the region of the mixer exit, even in the streamlined position.

The mixing plane Mach number and mixing potential within the virtual stream tube are essentially unchanged from the Baseline Mixer. Also, as with the Baseline Mixer, there is an accelerating fan flow path and constant area primary flow path as shown in Figure 5. In order to maintain the constant area primary flow path and the required mixing areas, a new plug contour was defined.

The first SWIXER configuration was judged to be susceptible to flow separation in the fan valleys due to the narrow channels produced by the swirl vanes and a strong diffusing region in the fan passage upstream of the mixer. To reduce this problem, the channel width was increased by reducing the number of lobes from 14 to 12, and the local flow turning was reduced by decreasing the fan valley angle from 22 to 17 degrees. In addition, the outer diameter of the fan duct upstream of the mixer was reduced to decrease the local diffusion in the mixer entrance duct and to provide a more energetic boundary layer flow in the fan valleys. Reducing the outer diameter of the entrance duct also reduces the possibility of low separation in a region on the duct outer wall aft of the MC2 flange.

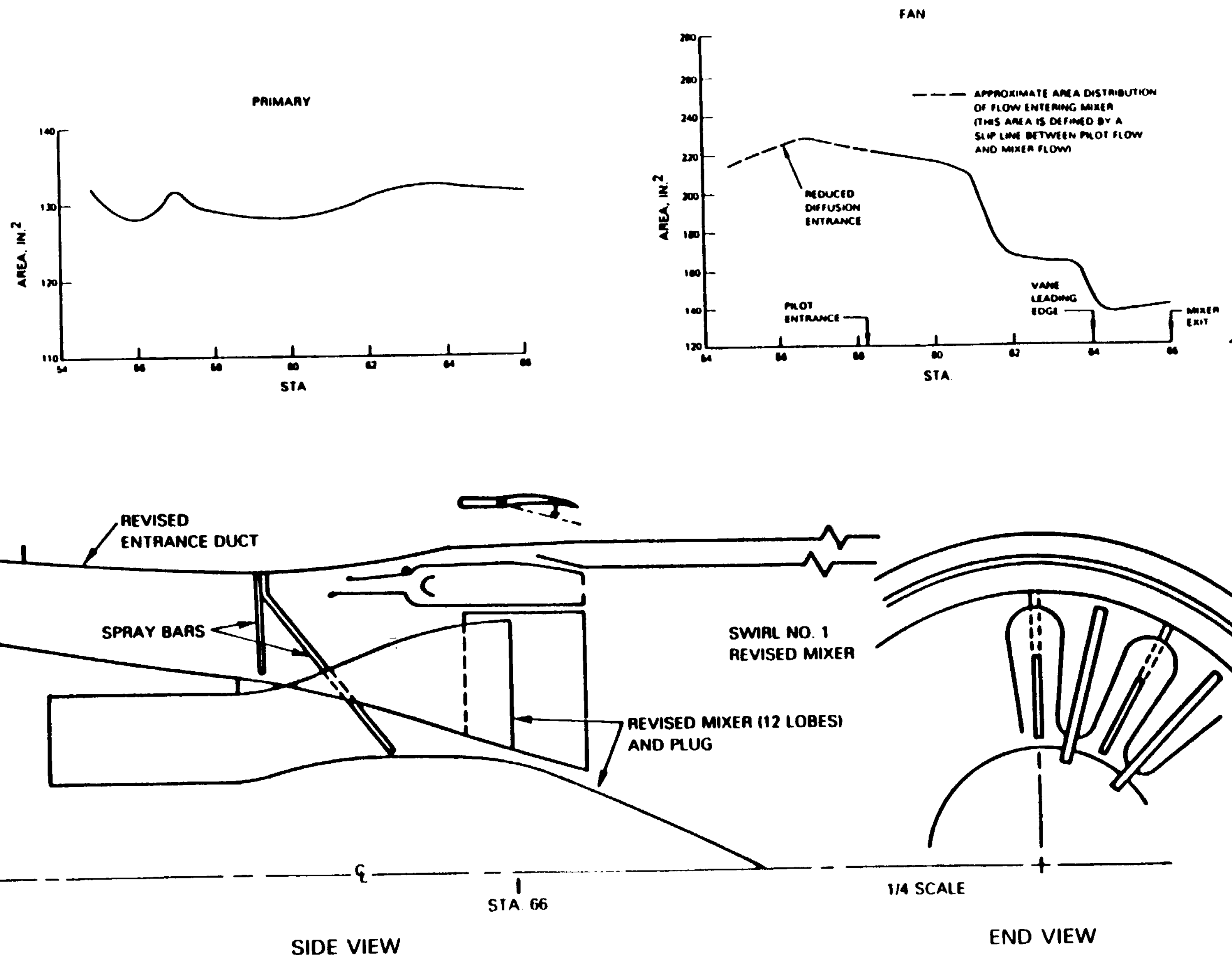


Figure 5 Mixer Flow Path Area Distribution SWIXER Final

The estimated ratio of displacement thickness to channel half-width in the fan lobes at the mixer exit ($\delta^*/ \ell/2W = .90$) exceeds the design criteria that was imposed on the baseline mixer ($\delta^*/ \ell/2W = .68$). The degree to which this design criteria was exceeded was minimized by reducing the diffusion rate in the fan duct upstream of the mixer to the extent that was possible without seriously compromising the augmentor flow path provided. Note, that the displacement thickness parameter is not intended to be a direct indication of when flow separation might occur. It has been used as a device to limit the design selection, whenever possible, to the range of design parameters reflected in our data base.

D. Baseline Flameholder Mixer

Description

The baseline flameholder mixer design, as shown in Figure 6, is a straight forward approach to the problem of combining mixer and augmentor technologies. Using accepted design practice from each field, a low risk design can be obtained.

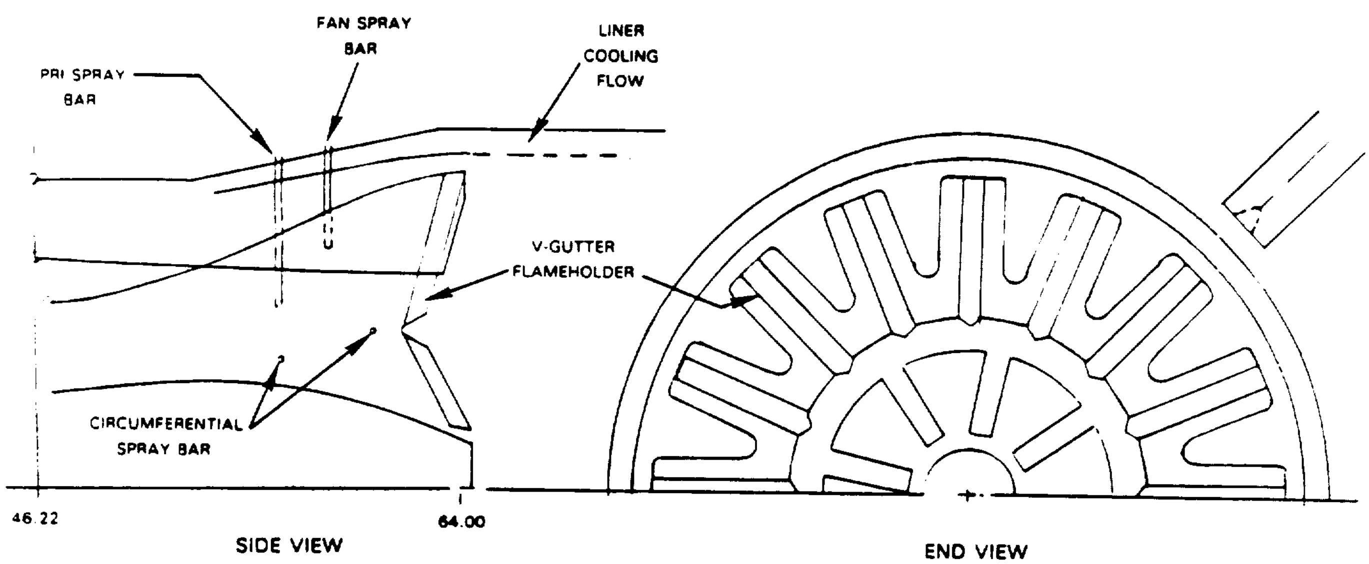


Figure 6 Preliminary Design Views of Baseline Flameholder Mixer

The baseline design uses a 32 lobe mixer (16 core and 16 fan lobes) with a V-gutter flameholder inset into the core stream. The flameholder serves to initiate combustion in the bulk of the gas stream flowing past. The flameholder has 16 OD V-gutters and 8 ID V-gutters attached to a circumferentially V-gutter pilot. The tips of the OD gutters contact the mixer. The walls of the hot chutes of the mixer are not radial, but are parallel to the enclosed radial flameholder. A similar mixer design was previously studied in full scale tests by Cullom and Johnsen (Ref. 2).

Fuel injection is provided by radial spraybars located in the center of each mixer chute. Fuel is injected in zones. The first zone provides fuel to the circumferential pilot ring for ignition and flame propagation to the radial gutters. The next zone to receive fuel is that containing the OD gutters. Only the core chutes receive fuel in this zone as the chutes contain the flameholders. The effect of the mixer is to flatten the augmentor exit temperature profile by increasing the mixing of unfueled fan air into the burdened core air, thus increasing thrust in the augmented mode. The third zone is that covered by the ID gutters. The final zone is fuel injected into the fan chutes. Because there is no flameholding device incorporated into the fan chutes, ignition is provided by the plane present in the core chutes. This reduces the rumble potential of the design by eliminating a recirculation volume in the cold stream in which the vaporization and energy release processes could interact with pressure pulsation.

A cooling liner is used approximately one inch from the ID of the case. The outer diameter of the mixer is approximately 0.7 inches from the ID of the cooling liner. The air for the cooling liner is picked up ahead of the static pressure balance plane and diffused. The cooling liner extends back to the exhaust nozzle.

The tailcone starts at the turbine exhaust case at 3.9 inch radius, expands to 4.4 inch radius then tapers to 1.8 inch radius where it is truncated. The tailcone forms the inner wall of a canted diffuser.

Rationale

The number of lobes is determined primarily from augmentor efficiency considerations. The major driver in the geometric effect on efficiency is the separation between the flameholders since this determines the point of closure of the flame front. The length and diameter then determines the flame residence time. Combustion in this design is a two step process: 1) an aerodynamic induced ignition of a streamtube and 2) non-luminous chemical reactions occuring downstream. The ignition and initial heat release takes place in the luminous flame front. The initial heat release is estimated at 50 percent of the total heat release. The chemical reactions and eddy mixing downstream of the luminous flame front add the remaining 50 percent of the heat release.

The positioning of the flameholders in the center of the hot chutes provides for increased flameholder stability, but it dictates the number of chutes due to the interaction between augmentor efficiency and flameholder number. Sixteen hot chutes require sixteen cold chutes.

E. Alternate Flameholder Mixer

Design Description

The alternate flameholder mixer design, as shown in Figure 7, attempts to increase the penetration of the cold chutes by distributing some of the blockage into the cold chute instead of concentrating all of it in the hot chutes. The method used was to design the flameholders into the trailing edge of the mixer.

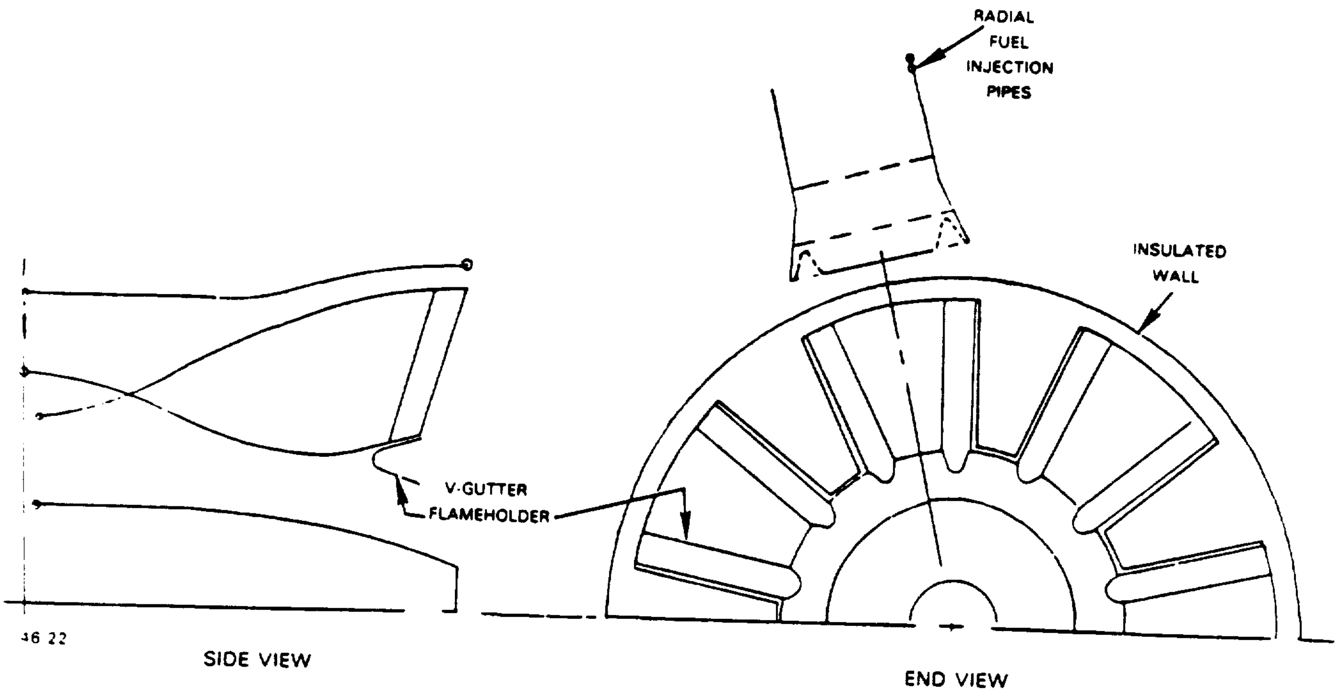


Figure 7 Preliminary Design Views of Alternate Flameholder Mixer

Fourteen radial flameholders are used. They are not attached to the mixer, to avoid thermal stresses, but are floating within the hot chutes. The mixer is designed to conform to the shape of the flameholder so that the wake contains both hot and cold stream gases. The flameholder is cooled by backside convection of the core stream gases. This serves to draw off the heat transferred from the flameholder wake to the flameholder and recirculate it into the wake. Due to the containment of both core and fan stream gas mixtures, the stability potential of this device is lower than that of the baseline flameholder mixer. Because the flight profile for this study only uses augmentation during takeoff and initial climb, the augmentor pressures are high enough to preclude stability problems.

To reduce the pressure loss in the system, the fuel spraybars are placed in the mixer sidewalls. Each spraybar will feed both a hot, vitiated flow and a cold, non-vitiated flow stream necessitating different orifice numbers and sizes on either side of the spraybar due to the variance in fuel requirements. Unlike the baseline flameholder mixer design, which zoned the flameholders circumferentially with the hot stream being fueled before the cold stream, this concept will be fueled radially. The fact that the F/H wake is composed of flow from both streams makes it essential that combustible mixtures be present in both streams or a blowout may occur. Although separately controlled spraybars for the hot and cold streams would be designed if a sizeable BRP excursion would take place over the operating envelope, for the narrow operational envelope contemplated it will be just as effective and less complex to use just one spraybar set for each annular zone.

No augmentor cooling liner is shown in this design. The case is instead protected by an insulating thermal blanket attached to the inner surface.

Rationale

This conceptual design attempts to improve on the operational characteristics of this system through use of some novel concepts. The major innovative concepts are the removal of the cooling liner and substitution of an internal insulating blanket directly on the duct wall, the placement of the flameholders in line with the mixer walls and the incorporation of the radial spraybars in the mixer walls.

No augmentor cooling liner is shown. To improve mixing efficiency and pressure loss characteristics at cruise, the liner was eliminated and replaced with insulating material attached to the inside surface of the case. A portion of the air near the case will not be burned during augmentation to provide a buffer layer for the nozzle. The augmentor operation time will be limited by the thermal transients in the case and nozzle. Because the augmentor in subsonic bomber applications is only used for takeoff and for flush time requirements, acceptable life should be attainable. Studies of military bomber engine requirements in the past have shown no requirement for maximum augmentation capability, so the decrease in maximum augmentation ratio required by this concept will result in no decrease in aircraft operational capability.

The placement of the flameholders in line with the mixer trailing edge results in approximately 2.9 inches greater penetration than the baseline design and should thus increase the mixing effectiveness. The wakes of the flameholders will provide an immediate mixing mechanism at the trailing edge of the flameholder due to the entrainment of both hot and cold gases. There is some concern, however, that the presence of the flameholders at the trailing edge of the mixer will decrease the size and strength of the vortices formed by the secondary flows and thus decrease the mixing due to that mechanism.

The fuel system is incorporated into the mixer walls to lower the pressure loss. The spraybars each inject fuel into both hot and cold streams in order to completely fill the flameholder wakes with a flammable mixture. This fuel injector design is different from the baseline design and will result in radial zoning with both hot and cold streams being fueled simultaneously. This compares to the baseline design which will fuel the core stream first, as the flameholders do not touch the fan stream at all.

The effect of both the removal of the cooling liner and the incorporation of the radial spraybars into the mixer wall will be to reduce the pressure loss of the system at all operating points. This will reduce TSFC at cruise conditions. The placement of the flameholders in line with the mixer wall provides for significantly greater penetration to aid the mixing.

F. Candidate Flameholder Aerodynamic Design

The initial or baseline flameholder design is a 14 lobed configuration with very little fan valley (bypass flow) penetration and very high flow blockage. This is mainly due to the location and number of V-gutters in the flow field. With the additional problem of analytically simulating their midlobe obstruction, it was jointly agreed that the alternate lobed flameholder configuration be approved for more detailed aerodynamic design and subsequent fabrication and testing.

The design of the final flameholder configuration was obtained modifying the design shown in Figure 7 to increase its duct commonality with the SWIXER installation, thereby focusing all analytical and experimental efforts only on the lobe shape and lobe number differences. The blockage effects of the V-gutters against the lobe side walls was assumed minimal and then therefore was neglected. The flow area distributions obtained using the SWIXER duct contours were then found to be with acceptable tolerances. A comparison of the revised design characteristics of the final flameholder mixer with improved on final SWIXER design is shown in Table III.

TABLE III
OVERVIEW OF REVISED

PRE-MIXER CHARACTERISTICS

	SWIXER Final	Flameholder Mixer Final
Lobes	12	6
Pilot	Yes	No
V/Gutters	No	Side Wall, 2/lobe
Penetration (Outer Wall)	64% 88% (Pilot)	87.6
L/D	1.25 (within Pilot)	2.0
Nozzle Exit Sta.	93.177	122
Lobe Shape	Radial No Sharp Corners	Radial Walls Sharp Corners
Fuel Injection	Fan & Primary Radial	Radial - Walls
Primary Gap	Small	Large
Flow Path Turning	Moderate	Fan = Reverse Turn Pri = Severe Turn
Cooling	Liner 2.6% Engine Flow	Insulation

III. DESIGN OF PLANAR MIXER CONFIGURATIONS

The two augmentor concept designs were modified in the previous section to reflect performance improvements identified using an empirically based design system. In a previous program (Ref. 3), detailed experimental data obtained for a JT8D-209 mixer installation indicated that the effect of total temperature ratio of the inlet streams can be effectively removed from the problem and that mixing effects can be considered in terms of total pressure differences alone. This simplification enables one to test using a cold flow facility to simulate real mixing effects.

"Planar" configurations refer to mixer lobes that are spanwise periodic but collapse to a flat plate at some upstream location. Planar configuration cannot be developed from most design systems derived only for "axisymmetric" or engine type applications. A geometrically "planar" analog to the axisymmetric augmentor can be obtained using the FLOMIX input preprocessor (Ref.4) while constraining several geometrical parameters to be constant. This is consistant with the design philosophy used in the axisymmetric for engine based mixer design system. The specific procedure followed was:

1) Increasing Rm and the number of lobes proportionately so that R_m/L_m 1 produces a planar surface with the same lobe width X, i.e.

$$X = 2\pi(R_m/N_{Lobe})$$

2) Maintaining the lobe turning angle, (L_m/h), implicitly maintains the lobe aspect ratio

$$AR = \frac{X}{h} = 2\pi\left(\frac{R_m}{N_{Lobe}}\right)\frac{1}{h}$$

3) The lobe penetration, $\underline{P} = \bar{A}_{pi}/A_{Duct}$, is implicitly maintained by maintaining the primary and bypass "flow" areas, i.e.

$$A_{Nozzle} - A_{Rm} = \text{constant} \rightarrow R_{Nozzle}$$

$$A_{Rm} - A_{centerbody} = \text{constant} \rightarrow R_{centerbody}$$

The planar equivalent of the SWIXER and flameholder mixer configurations were then scaled to fit in the UTRC planar wind tunnel with an even number of mixer lobes. A description of this wind tunnel is provided in Part I of this report series. A comparison of these two planar lobes at the trailing edge plane demonstrates that two SWIXER lobes evenly fit within the gap of one flameholder lobe. Figure 8 illustrates the fabricated SWIXER lobe with a simulated turning vane in the UTRC test facility while Figures 9 and 10 shows two uninstalled views of the fabricated flameholder design.

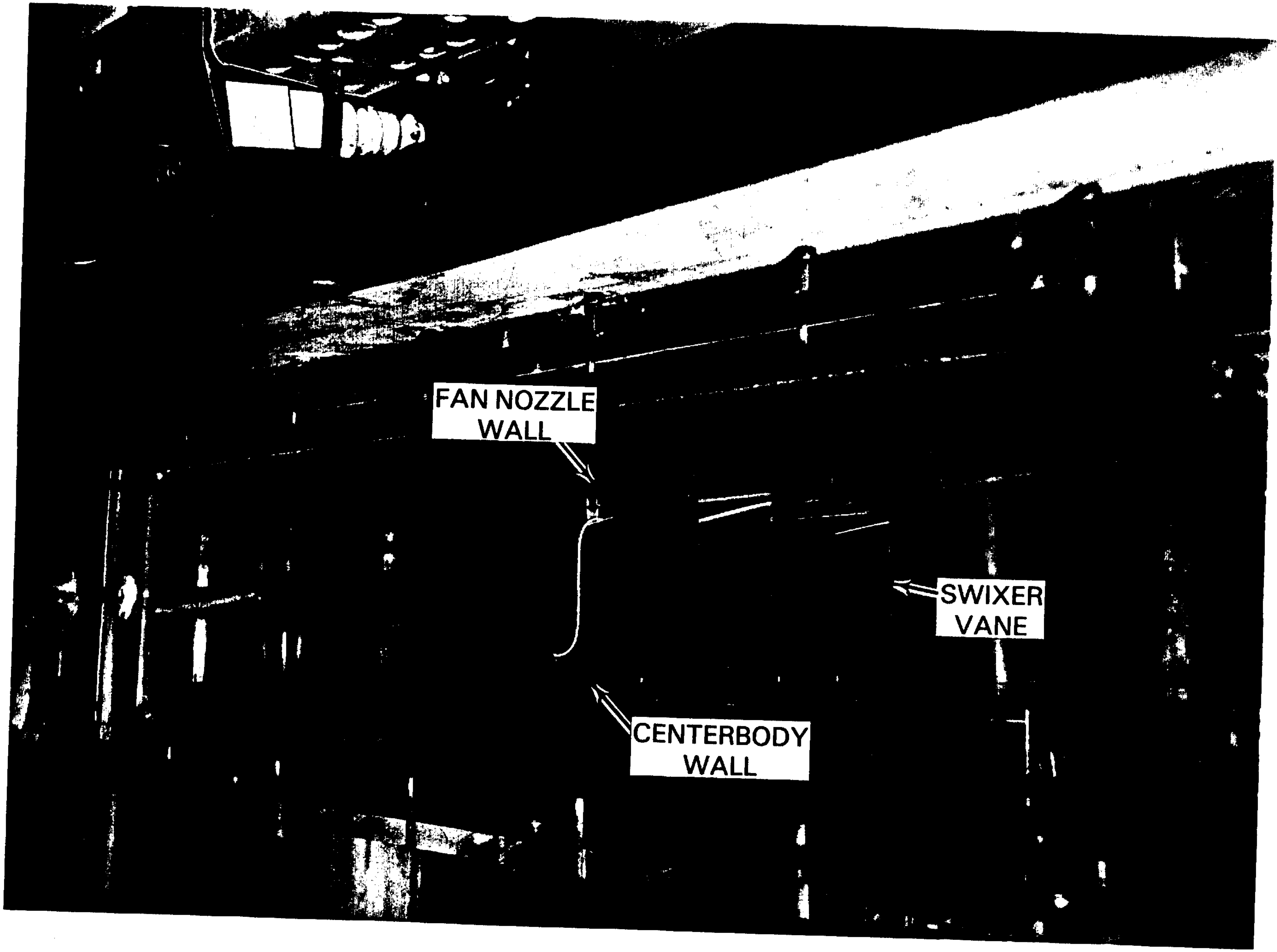


Figure 8 Installed View of SWIXER With Vane in Planar Wind Tunnel

ORIGINAL PAGE IS
OF POOR QUALITY

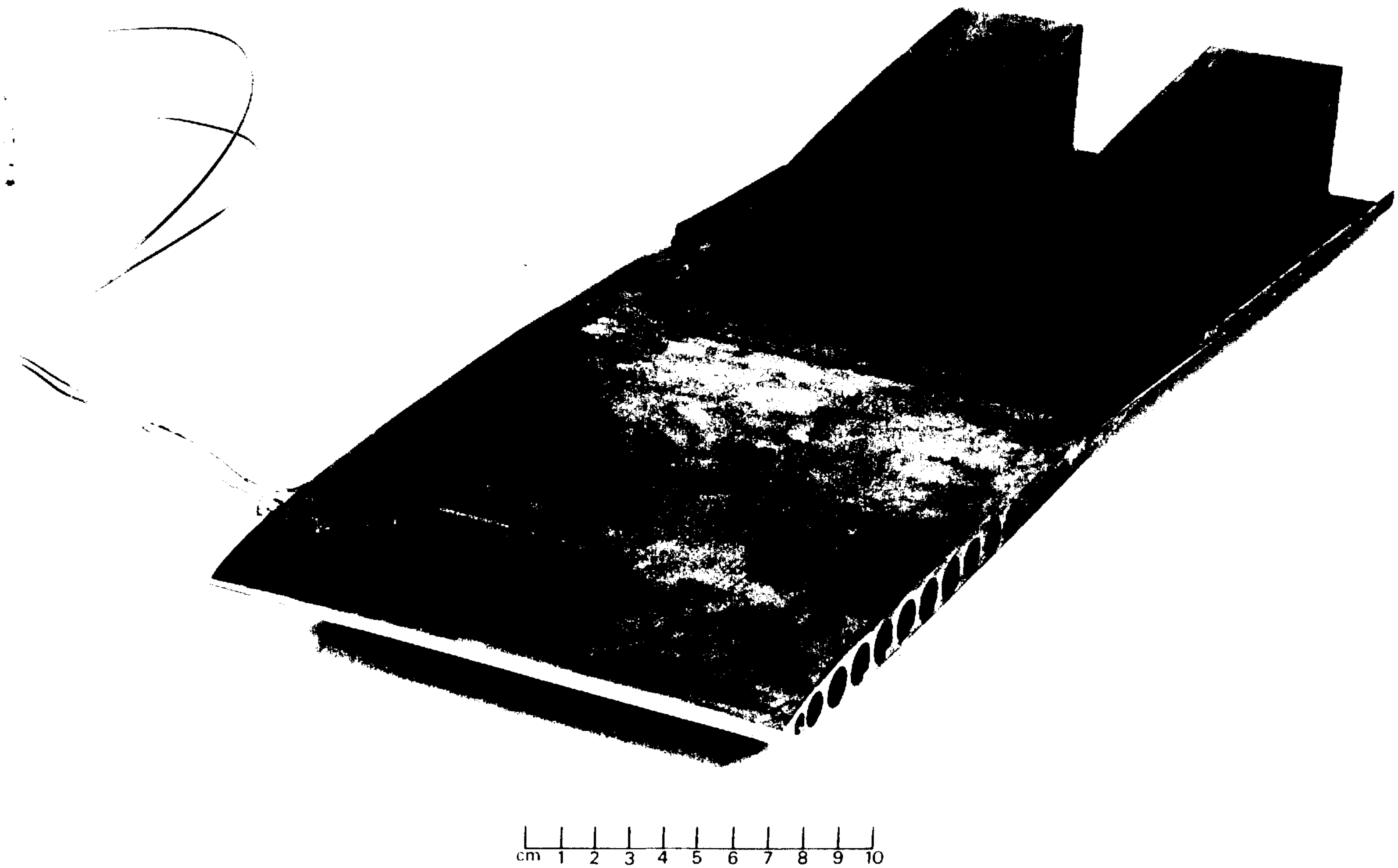


Figure 9 Downstream View of Flameholder Mixer Assembly

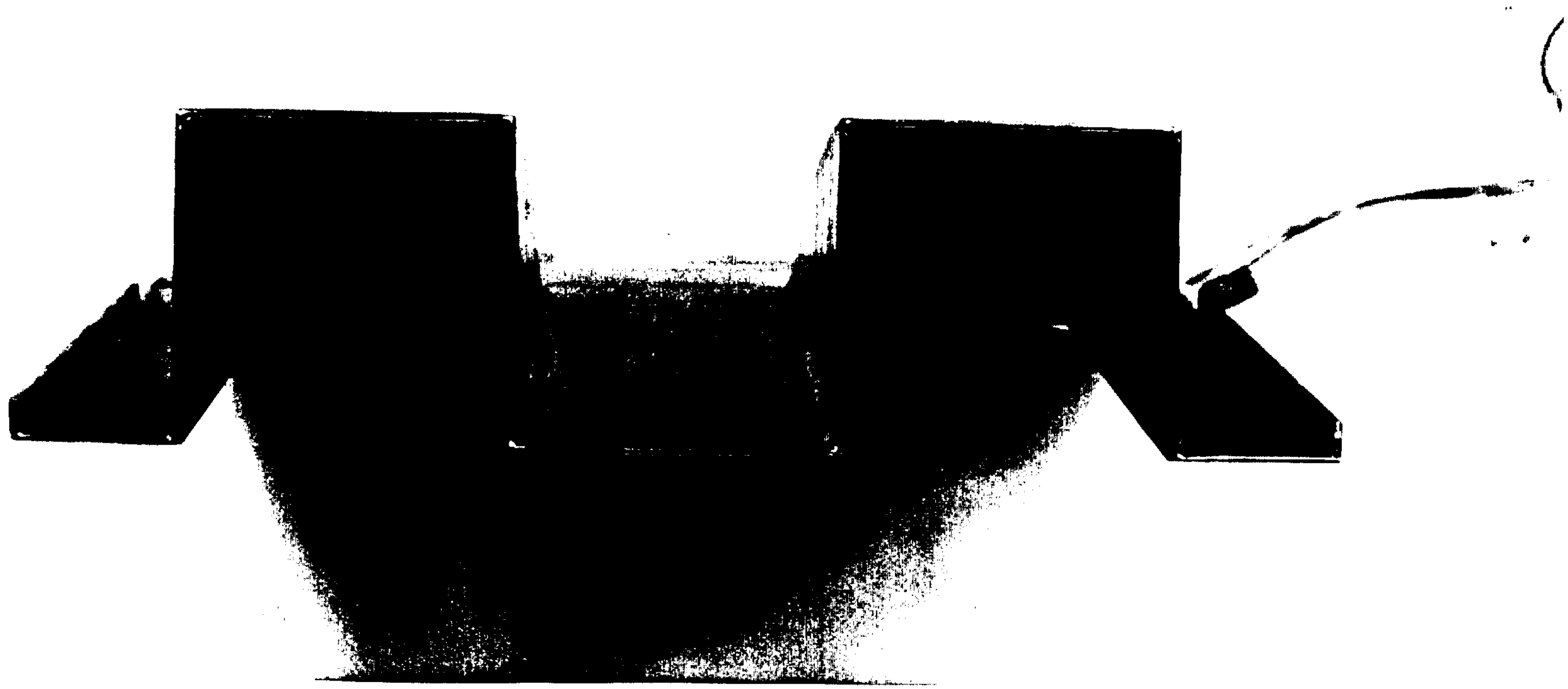


Figure 10 Trailing Edge View of Flameholder Mixer Assembly

IV. EXPERIMENTAL ASSESSMENT OF SWIXER DESIGN

A comprehensive experimental study of the SWIXER configuration without vanes installed is reported in Part I of this report series under the model designation, "Advanced High Penetration Mixer". A limited experimental assessment of the SWIXER configuration (vanes installed) was conducted using flow visualization and laser Doppler velocimetry (LDV) techniques similar to those reported in Part I. A limited assessment was conducted since surface flow visualization on the lobe surfaces showed no appreciable changes due to introduction of the vanes. Furthermore, the vane position in the center of the fan trough would not be expected to interfere with secondary flow cells which center on the dividing surface between the troughs and peaks, i.e. the plane of the vane represents a plane of symmetry.

To further identify the general similarity of flow patterns, the spanwise secondary flow component was measured* with a LDV at an axial location ($X = 0.05$)** just downstream of the vanes. This pattern is shown in a contour plot format in Figure 11. A corresponding plot for the configuration without vanes is shown in Figure 12. The latter data were obtained at an axial location ($X = 0.05$) downstream of the lobe trailing edge, and hence in physical location, $x = 3.75$ upstream of the survey with vanes.

A detailed discussion of the results shown in Figure 12 for the model without vanes is provided in Part I. It was concluded that the opposite directed components in the vicinity of the vertical lobe surfaces was due to flow filling in the wake of blunt-based 0.060 thick lobe trailing edge. This is a localized event which would not be expected to persist in the vane configuration survey due to wake mixing. As shown in Figure 11, these cross-stream flows are not observed at the vane exit station. Instead, Figure 12 for the SWIXER, shows a corresponding cross-flow pattern at the vane trailing edge due to the same wake-filling mechanism. Excluding these localized trailing edge wake patterns, the cross-flow components for the two configurations are similar and generally of low magnitude. From these results as well as the improved understanding of mixer lobe secondary flow generation presented in Part I, it is concluded that SWIXER configurations at zero vane angle can be analyzed using the same basic methods developed for non-vane configurations. Specifically, the secondary flow circulations responsible for downstream mixing should scale with geometrical parameters in the manner described in Part I.

---

*LDV survey data for SWIXER with and without vane are presented in Appendix A and B, respectively.

** All coordinates consistent with Part I definitions have been normalized by the lobe half width.

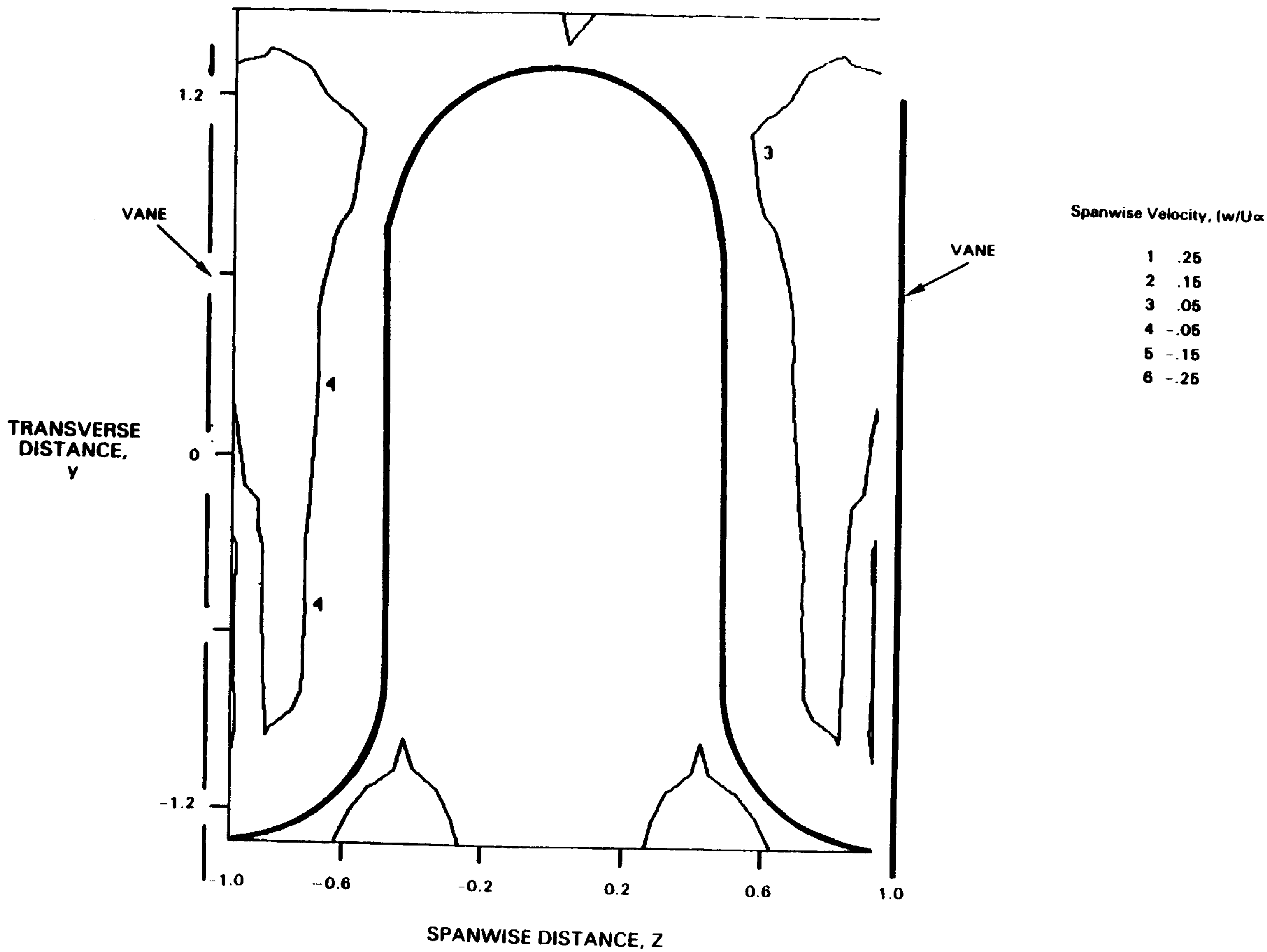


Figure 11 Contour Plot of Spanwise Velocity Component at Trailing Edge of SWIXER Lobe, With Vane Installed

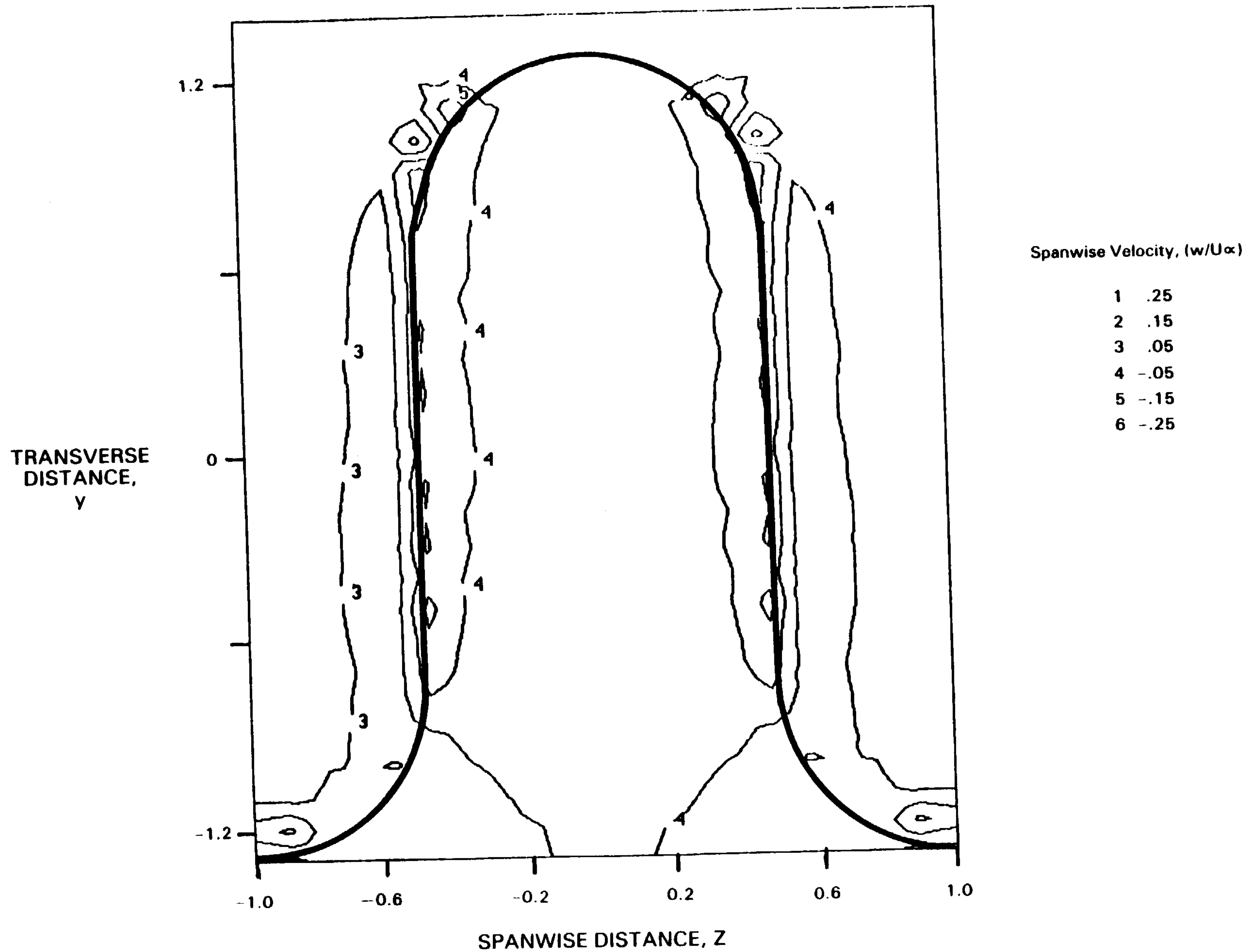


Figure 12 Contour Plot of Spanwise Velocity Component at Trailing Edge of SWIXER Lobe, Without Vane Installed

V. REFERENCES

1. Sokhey, S.S., "Experimental Performance Evaluation of Ventilated Mixers - New Concept for High Bypass Turbofan Engines", AIAA/SAE, ASME 18th Joint Propulsion Conference, Cleveland, OH, 1982.

2. Cullom, R.R., and Johnson, R.L., "Altitude Engine Test of a Turbofan Exhaust Mixer to Conserve Fuel", ASME J. Eng. Power, Trans. A, No 99, Vol 4, 1977, p 645.

3. Paterson, R.W., "Turbofan Forced Mixer-Nozzle Internal Flowfield, I -A Benchmark Experimental Study", NASA CR 3492, 1982, also J. Eng. for Gas Turbines & Power, Vol. 106, 1984, p. 692.

4. Barber, T.J., Muller, G.L., Ramsay, S.M., and Murman, F.M., "Three Dimensional Inviscid Flow in Mixers, Part I: Analysis Using a Cartersian Grid," AIAA J. Propulsion & Power, Vol. 2, No. 3, 1986, p. 275.

5. Barber, T.J., Muller, G.L., Ramsay, S.M., and Murman, F.M., "Three Dimensional Inviscid Flow in Mixers, Part II: Analysis of Turbofan Forced Mixers, AIAA J. Propulsion & Power, Vol. 2, No. 4, 1986, p. 339.

APPENDIX A

SWIXER WITHOUT VANE LOBED MIXER (w/U∞)

Normalized Spanwise Velocity LV Data

Axial Location X = 0.05

J	Y (IN) \ Z (IN)	0.07	0.17	0.27	0.37	0.47
1	1.40	0.0028	0.0157	0.0233	0.0271	0.0285
2	1.30	0.0001	0.0158	0.0271	0.0375	0.0349
3	1.20	-0.0089	-0.0079	-0.0251	0.0323	0.0370
4	1.10	-0.0097	0.0159	0.0660	0.2186	0.0048
5	1.00	-0.0057	0.0088	0.0469	0.1004	-0.1818
6	0.90	-0.0050	0.0172	0.0346	0.0771	0.1912
7	0.80	-0.0016	0.0180	0.0345	0.0737	0.1745
8	0.70	0.0026	0.0185	0.0318	0.0614	0.1453
9	0.60	-0.0011	0.0120	0.0268	0.0657	0.1454
10	0.50	-0.0017	0.0157	0.0243	0.0527	0.1344
11	0.40	-0.0026	0.0138	0.0251	0.0606	0.1571
12	0.30	-0.0028	0.0157	0.0231	0.0549	0.1478
13	0.20	-0.0008	0.0151	0.0253	0.0614	0.1574
14	0.10	-0.0004	0.0121	0.0256	0.0641	0.1453
15	0.00	0.0002	0.0146	0.0292	0.0654	0.1066
16	-0.10	-0.0033	0.0143	0.0253	0.0654	0.1589
17	-0.20	-0.0027	0.0086	0.0222	0.0525	0.1471
18	-0.30	-0.0027	0.0116	0.0201	0.0580	0.1609
19	-0.40	-0.0034	0.0057	0.0173	0.0491	0.1069
20	-0.50	-0.0072	0.0050	0.0094	0.0513	0.1795
21	-0.60	-0.0031	-0.0010	0.0037	0.0336	0.1305
22	-0.70	-0.0108	-0.0057	-0.0061	0.0220	0.1056
23	-0.80	-0.0157	-0.0124	-0.0150	-0.0065	0.0295
24	-0.90	-0.0179	-0.0230	-0.0271	-0.0373	-0.0594
25	-1.00	-0.0174	-0.0323	-0.0423	-0.0528	-0.0751
26	-1.10	-0.0215	-0.0357	-0.0506	-0.0647	-0.0853
27	-1.20	-0.0228	-0.0498	-0.0574	-0.0734	-0.0807
28	-1.30	-0.0355	-0.0578	-0.0655	-0.0804	-0.0912

SWIXER WITHOUT VANE LOBED MIXER (w/U∞)

Normalized Spanwise Velocity LV Data

Axial Location X = 0.05

J	Z (IN) / Y (IN)	0.57	0.67	0.77	0.87	0.97
1	1.40	0.0171	0.0142	0.0080	-0.0019	-0.0056
2	1.30	0.0253	0.0231	0.0153	0.0012	-0.0070
3	1.20	0.0271	0.0217	0.0165	0.0079	-0.0004
4	1.10	0.0230	0.0176	0.0168	0.0093	0.0035
5	1.00	0.0032	0.0097	0.0122	0.0100	0.0029
6	0.90	-0.0302	-0.0022	0.0072	0.0028	0.0020
7	0.80	-0.0662	-0.0247	-0.0034	0.0028	0.0033
8	0.70	-0.0917	-0.0360	-0.0133	-0.0007	0.0018
9	0.60	-0.1084	-0.0468	-0.0180	-0.0063	0.0002
10	0.50	-0.1207	-0.0496	-0.0226	-0.0088	-0.0004
11	0.40	-0.1236	-0.0515	-0.0241	-0.0104	-0.0015
12	0.30	-0.1243	-0.0544	-0.0270	-0.0122	-0.0031
13	0.20	-0.1193	-0.0518	-0.0291	-0.0124	-0.0029
14	0.10	-0.1064	-0.0517	-0.0277	-0.0180	-0.0016
15	0.00	-0.1158	-0.0560	-0.0300	-0.0157	-0.0031
16	-0.10	-0.1198	-0.0588	-0.0288	-0.0153	-0.0021
17	-0.20	-0.1114	-0.0647	-0.0290	-0.0186	-0.0006
18	-0.30	-0.1131	-0.0619	-0.0312	-0.0194	-0.0031
19	-0.40	-0.1093	-0.0621	-0.0330	-0.0190	-0.0025
20	-0.50	-0.1151	-0.0619	-0.0316	-0.0191	-0.0055
21	-0.60	-0.1132	-0.0562	-0.0319	-0.0193	-0.0031
22	-0.70	-0.0997	-0.0518	-0.0316	-0.0244	-0.0061
23	-0.80	-0.0962	-0.0548	-0.0333	-0.0247	-0.0101
24	-0.90	-0.0753	-0.0574	-0.0317	-0.0229	-0.0039
25	-1.00	-0.0460	-0.0564	-0.0428	-0.0173	-0.0193
26	-1.10	-0.1147	-0.1478	-0.0599	-0.0321	-0.0349
27	-1.20	-0.0890	-0.0998	-0.0978	-0.2672	-0.2096
28	-1.30	-0.0865	-0.0910	-0.0675	-0.0308	-0.0186

APPENDIX B

SWIXER WITH VANE LOBED MIXER (w/U∞)

Normalized Spanwise Velocity LV Data

Axial Location X = 0.05

J	Y \ Z	0.03	0.13	0.23	0.33	0.43	0.53
1	1.50	-0.0597	-0.0472	-0.0318	-0.0143	-0.0112	-0.0093
2	1.30	-0.0413	-0.0290	-0.0023	0.0159	0.0258	0.0259
3	1.10	-0.0405	-0.0207	0.0013	0.0326	0.0323	0.0453
4	0.90	-0.0245	-0.0086	0.0001	0.0008	0.0137	0.0371
5	0.70			0.0068	0.0184	0.0172	0.0332
6	0.50	-0.0164	-0.0103	0.0009	0.0121	0.0090	0.0137
7	0.30	-0.0200	-0.0115	0.0012	0.0002	-0.0037	0.0051
8	0.10	-0.0192	-0.0120	-0.0087	-0.0033	-0.0065	-0.0021
9	-0.10	-0.0193	-0.0101	-0.0118	-0.0030	0.0024	0.0017
10	-0.30	-0.0198	-0.0139	-0.0141	-0.0079	-0.0084	-0.0106
11	-0.50	-0.0185	-0.0119	-0.0096	-0.0041	-0.0054	-0.0139
12	-0.70	-0.0205	-0.0208	-0.0178	-0.0137	-0.0127	-0.0157
13	-0.90	-0.0199		-0.0263	-0.0249	-0.0482	-0.0218
14	-1.10	-0.0214	-0.0220	-0.0324	-0.0489	-0.0563	-0.0491
15	-1.30	-0.0129	-0.0253	-0.0396	-0.0666	-0.0906	-0.0866

J	Y \ Z	0.63	0.73	0.83	0.93
1	1.50	-0.0051	0.0107	0.0145	-0.0504
2	1.30	0.0293	0.0540	0.0687	0.0580
3	1.10	0.0619	0.0723	0.0846	0.0740
4	0.90	0.0626	0.0893	0.0942	0.0761
5	0.70	0.0412	0.0869	0.0936	0.0837
6	0.50	0.0126	0.0772	0.0867	0.0648
7	0.30	0.0181	0.0734	0.0775	0.0541
8	0.10	0.0055	0.0735	0.0742	0.0471
9	-0.10	-0.0061	0.0668	0.0733	0.0378
10	-0.30	-0.0048	0.0550	0.0690	-0.0642
11	-0.50	-0.0135	0.0558	0.0645	-0.0568
12	-0.70	-0.0016	0.0520	0.0611	-0.0563
13	-0.90	-0.0089	0.0472	0.0509	-0.0633
14	-1.10	-0.0273	0.0313	0.0460	-0.0375
15	-1.30	-0.0512	0.0263	0.0414	-0.0056

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-4147		

4. Title and Subtitle	5. Report Date
Turbofan Forced Mixer Lobe Flow Modeling III - Application to Augment Engines	October 1988
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
T. Barber, G.C. Moore, and J.R. Blatt	None (E-4085)
	10. Work Unit No.
	505-62-21
9. Performing Organization Name and Address	11. Contract or Grant No.
United Technologies Corporation Pratt & Whitney Engineering Division East Hartford, Connecticut	NAS3-23039
	13. Type of Report and Period Covered
	Contractor Report Final
12. Sponsoring Agency Name and Address	14. Sponsoring Agency Code
National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191	

15. Supplementary Notes

Project Manager, Allan R. Bishop, Internal Fluid Mechanics Division, NASA Lewis Research Center.

16. Abstract

Military engines frequently need large quantities of thrust for short periods of time. The addition of an augmentor can provide such thrust increases but with a penalty of increased duct length and engine weight. The addition of a forced mixer to the augmentor improves performance and reduces the penalty, as well as providing a method for siting the required flame holders. In this report two augmentor concepts have been investigated; a swirl-mixer augmentor and a mixer-flameholder augmentor. Several designs for each concept are included and an experimental assessment of one of the swirl-mixer augmentors is presented.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Mixers Lobe flow modeling Three-dimensional flows	Unclassified - Unlimited Subject Category 02

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No of pages	22. Price*
Unclassified	Unclassified	36	A03

NASA FORM 1626 OCT 86

*For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-Langley, 1988

National Aeronautics and
Space Administration
Code NTT-4

Washington, D.C.
20546-0001

NASA